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Descriptive Analysis for Computer-Based Decision Support

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DESCRIPTIVE ANALYSIS FOR COMPUTER-BASED DECISION SUPPORT

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DESCRIPTIVE ANALYSIS FOR COMPUTER-BASED DECISION SUPPORT

Abstract

This article studies the issue of descriptive analysis for Decision Support Systems (DSS). Much of the DSS research literature concentrates on the procedural aspects of building support systems rather than on the substantive issues of their content. If we are to expand further our knowledge of DSS, however, it is important to complement our understanding of the process of DSS development with a means for describing and differentiating DSS. In particular, a descriptive mechanism should pay careful attention to those features of DSS that determine the effects a support system has on the decision-making processes of its users.

A three-tiered approach to describing DSS is proposed, consisting of the following sequence of analytical levels: functional capabilities, user views of system components, and system attributes (restrictiveness, guidance, and focus). Moving from the first through the third tiers, increasing attention is paid to examining DSS in their entirety and to considering their effects on decision-making processes. Implications for further research are highlighted.

DESCRIPTIVE ANALYSIS FOR COMPUTER-BASED DECISION SUPPORT

For Decision Support Systems (DSS) to continue to flourish as a field of research, it is essential that we be able to describe the objects of our study, namely, Decision Support Systems. Just as physicists employ mathematical equations and chemists enlist molecular models as descriptive tools, so too can DSS researchers make good use of a means of describing the systems they study. Indeed, virtually every area of DSS research activity could benefit from a good descriptive mechanism for DSS.

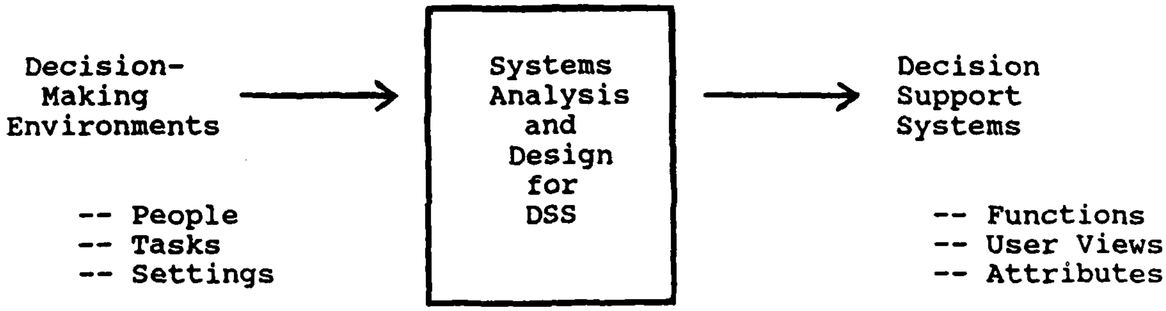
Consider, for example, research concerning DSS analysis and design. One of the central concepts in the literature is that DSS must be tailored to the specific decision-making environments they support. It is useful, therefore, to think of systems analysis and design as a matching process, a function that accepts decision-making environments as inputs and produces corresponding computer-based information systems as outputs (see Figure 1). The goal is to create or to select that one computer-based system from the universe of possible systems that best meets the needs of the environment. The DSS analysis and design processes could be both more efficient and more effective if meaningful knowledge bases could be used to support this effort. These knowledge bases must

- identify and describe the key characteristics of people, tasks, and organizational settings to be considered;
- describe how DSS differ from one another and how those differences affect the way decisions are likely to be made; and
- prescribe a mapping that translates characteristics of environments into characteristics of the systems that support them.

The challenge for DSS researchers is to create and expand these DSS knowledge bases. The ultimate goal--not yet on the horizon and perhaps not fully attainable--is a prescriptive mapping from environments to systems. Before we can even consider such

Figure 1

Simple Model of Systems Analysis and Design



prescription, however, we must first have more meaningful description. The immediate focus of research attention should, therefore, be on developing appropriate means for describing and differentiating environments and, especially, systems.

To date, a relatively small share of DSS research has addressed these issues. The most widely read portion of DSS research has addressed the "procedural" issues of building systems rather than the "substantive" questions concerning their content. For instance, the terms "Adaptive Design" (Keen, 1980), "Middle-Out Design" (Ness, 1975; Hurst et al., 1983), "Evolutionary Development" (Grajew and Tolovi, 1978; Hurst et al., 1983), and others like them dominate the DSS literature. While the concept of involving users in an evolutionary development process is no doubt important, the time has now come to ask the question: What do we do substantively as we proceed to design in an adaptive, middle-out, and evolutionary manner?

Within the relatively small segment of the DSS literature that is descriptive, decision-making environments have received far greater attention than have Decision Support Systems themselves. In fact, a number of promising characteristics--for instance, task structure (Mason and Mitroff, 1973; Lerch and Mantei, 1984), task interdependency (Hackathorn and Keen, 1981), and organizational style (Huber, 1981)--have been proposed

for categorizing environments. To a large extent, however, these characteristics have remained loose ends in the literature. They have been introduced--and in some cases widely cited--but never developed. There is little to indicate how these environmental differences might translate into differences in systems. We are left to conclude that the mapping would be an identity: Type "X" systems would be built for type "X" environments.

Perhaps the reason these characteristics--the inputs to the design process--could not be pushed further is that so little attention has been paid to the outputs, the Decision Support Systems themselves. Other than Alter's (1980) now dated taxonomy, we have done relatively little to describe how DSS differ from one another. In particular, we have not confronted what ought to be the central substantive issue in DSS design: how features of DSS affect decision-making processes.

All in all, it is quite surprising that the description and differentiation of Decision Support Systems have received so little research attention. The purpose of this study is to begin to remedy that situation by exploring ways in which Decision Support Systems can be described and compared. A three-tiered approach will be employed.

1. Objectives

One can imagine any number of different schemes for describing a particular Decision Support System. What, then, are the criteria against which a descriptive mechanism should be judged? Generally speaking, the objective is to enlighten both research and practice. That is, the descriptive mechanism should provide a better understanding of the object under study--in this case, DSS--and it should also facilitate further research, thus serving as the basis for still greater understanding in the future.

More specifically, a good descriptive mechanism will have a number of desirable properties. First, the mechanism should be applicable to all aspects of the study of DSS. Every DSS research area depends upon having some means of describing DSS, and every research area can benefit from a good descriptive mechanism. Different research questions,

however, may require different types of descriptions. An important objective, therefore, is that the descriptive mechanism be sufficiently complete to serve the full range of DSS research needs.

Having a common mechanism for describing DSS can facilitate communication among researchers and can contribute to establishing a cumulative, integrated research base. For researchers working on the same or closely related problems, sharing the same method of description can make it easier to compare findings with one another. For researchers concentrating on different topics, the common mechanism provides a means for linking the various components of DSS research to construct a more complete picture of the field.

The descriptive mechanism must also link researchers with practitioners. Researchers must be able to use it as a vehicle to convey their findings to practitioners concerning the appropriate use of new and existing decision-aiding techniques. The descriptive schema must serve ultimately as the basis for a prescriptive mapping from characteristics of decision-making environments to features--that is, characteristics--of Decision Support Systems. In the meantime, the schema can enlighten DSS practice by helping implementors identify the key elements in the design and selection of DSS.

Simply being able to describe Decision Support Systems is not sufficient. A good mechanism will also help differentiate DSS from one another, often an important activity in DSS research. Consider Figure 2, which augments Figure 1 to include system use as well as systems analysis and design. The inputs to the process of system use are the decision-making environment and the DSS, and the outputs are decisions. The various entities, processes, and relationships in the diagram suggest numerous research questions, many of which depend upon the ability to differentiate DSS appropriately. Among these questions are the following:

- Do different analysis and development processes systematically produce DSS with different characteristics?
- Should different types of decision-making environments be supported by DSS with different characteristics?

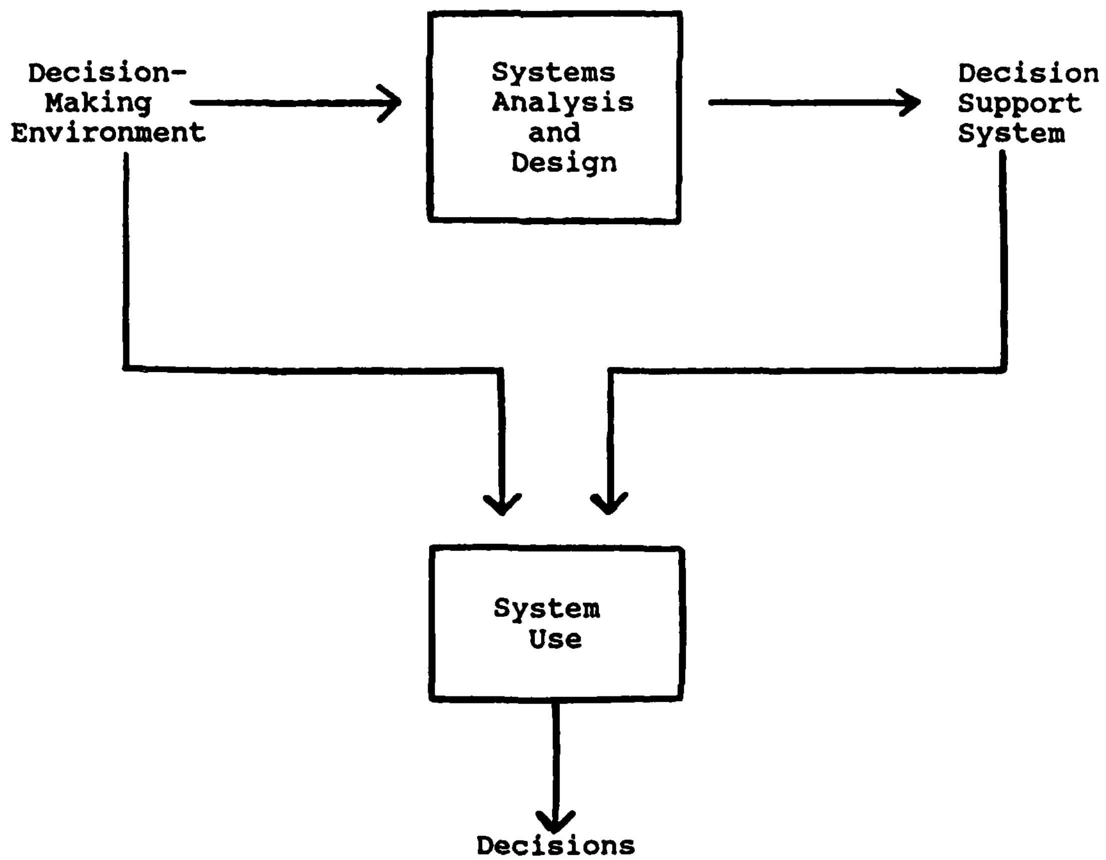
- Does the use of DSS with different characteristics systematically lead to different decision-making behavior and/or different decisions?
- Are DSS with some characteristics more likely to be used than those with others?

A necessary foundation for studying each of these problems is a means of describing not just DSS, but differences among DSS.

Most of the aforementioned objectives apply equally well to describing any computer-based information system. The uniqueness of describing systems that support decision makers is found in the need to present the decisional qualities of the system.

Figure 2

Schematic Interpretation of Some DSS Research Issues



That is, a useful schema must capture how a system is likely to affect the way in which decisions are made and must distinguish systems in terms of their likely effects on decision-making behavior. Indeed, understanding how Decision Support Systems affect managerial decision making is and must be a major objective of DSS research.

The intuitive notion of computer-based decision support is that of an information-processing assistant, a cognitive or organizational aid. From this perspective, the role of a DSS is seen as augmenting a human decision maker's limited information-processing capabilities. Such a view leads to descriptive mechanisms focusing on the added information-processing functionality that a system makes available to decision makers.

This intuitive notion, however, is not complete. DSS must be recognized as not merely augmenting the decisional machinery but as intervening in the decision-making process. The introduction of a DSS into a decision-making environment changes the set and sequence of information-processing activities performed enroute to arriving at a decision. A good descriptive mechanism, therefore, must pay special attention to those features of DSS that affect the way in which decisions are reached. While the proposed approach to DSS description satisfies all of the objectives just enumerated, special emphasis is placed on comprehending the relationship between the Decision Support System and the decision-making process.

2. A Three-Tiered Approach

Any simple descriptive schema for DSS will not easily satisfy the multiple objectives just set forth. It is equally undesirable to try to cover the various objectives with a set of several independent descriptive mechanisms. Consequently, the approach taken here is to consider a sequence of three levels of description, with each tier building on the descriptions generated by the previous levels of analysis.

The three analytic tiers--based on Silver (1986) and shown schematically in

Figure 3--describe a Decision Support System in terms of

1) its functional capabilities,
2) its configuration as viewed by its users, and
3) its attributes as a "whole" system.

These tiers correspond to three questions commonly asked by DSS users:

1) "What can it do?"
2) "What does it look like?"
3) "How will it affect my decision making?"

Figure 3

A Three-Tiered Schema for Describing DSS

```
                --------------------------
Third:          |    System Attributes    |
                --------------------------
                       ||         ||
                       ||         ||               Increasing
                --------------------------         Attention to
Second:         | User View of Components |        Entire DSS and
                --------------------------         to Decision-
                       ||         ||               Making Processes
                       ||         ||
                --------------------------
First:          | Functional Capabilities |
                --------------------------
```

As we move upward from the first through the third tier, two shifts of perspective become apparent. First, the descriptions pay increasing attention to decision-making processes and to the perspective of DSS as process interventions. Second, the descriptions take more and more of a holistic outlook rather than focusing on the individual system components in isolation from one another. As a result, the uppermost tier plays a central and innovative role in achieving the descriptive objectives.

3. The First Tier: Functional Capabilities

The most basic--and most commonplace--way of describing a Decision Support System is in terms of what it does. This first descriptive level addresses the intuitive notion of DSS as information-processing assistant, identifying the information-processing capabilities that a particular DSS offers its users. "Solves linear programs," "solves the product-mix linear program," "allows ad hoc queries of historical sales data," "graphs inventory levels over time," "forecasts income and expense," and "performs multi-attribute utility calculations" are all examples of functional descriptions of DSS capabilities.

While some DSS perform a single function, most DSS will include a number of different information-processing capabilities. A functional description of these systems could be as simple as the "laundry list" of functions--that is, information-processing capabilities--commonly used by software salesmen and DSS developers to promote their products. Indeed, such lists could also serve as the basis to compare different DSS. In order to truly understand the role of a DSS in supporting managerial decision making, however, we desire a more informative means of describing a system's capabilities. We need a mechanism that sheds light on which information-processing functions are appropriate in a given situation, as well as one that facilitates comparing capabilities across systems. In short, we need a consistent means to classify functions.

An early classification effort was Alter's (1980) seven-category taxonomy, based on the "degree of action implication of system outputs." Alter's work was a classification scheme for the DSS of its day, but today its categories apply better to individual functions within a single system. The scheme has greater historical significance than ongoing importance, however, and is not sufficiently detailed for our present purposes.

The functional capabilities of a DSS are generally intended to be responsive to the decision-making needs of its users. Indeed, decisional needs are the chief inputs to the analysis and design process that produces DSS. What better way to classify support functions, then, than by associating them with the managerial needs they meet?

Fuller exploration of alternatives, earlier detection of problems, and coping with multiple or undefined objectives are but a few of the needs commonly felt by decision makers. Each of these represents an obstacle to reaching a decision, an element of problem-solving activity that, when present, makes decision making difficult. The difficulties that humans and organizations encounter in making decisions, in turn, create the potential for computer-based support systems to be of value. To understand the functional capabilities of a DSS, therefore, is to comprehend if and how the functionality helps managers satisfy these and other decisional requirements.

Identifying the needs associated with particular DSS functions should be a natural process for both DSS researchers and practitioners. Nonetheless, it is easy to become preoccupied with analyzing DSS capabilities in terms of their information-processing functions rather than with respect to their decisional roles. "Graphs data," "queries databases," and "solves optimization models" are all perfectly good descriptions of what a system does, but they do not convey why the system does what it does. The phrases do not inform us why it matters to a decision maker whether these functions are or are not included in the system. The phrases do not capture the effect these functions can have on the way in which decisions are reached.

Augmenting simple descriptions of functions with analyses of the decisional needs they meet would be most valuable. For instance, if the functional capability being described is "graphs data," does the system graph historical data for the purpose of detecting problems, or does it graph projected data for the purpose of exploring alternative courses of action? These are the kinds of questions that a functional description must answer if it is to help us understand the role of the DSS in supporting problem solving.

Decision-making needs can be expressed in more or less general terms. Each of the needs mentioned previously--exploration of alternatives, earlier detection of problems, and coping with multiple or undefined objectives--applies to a broad range of situations because it is expressed very generally. On the other hand, "solving my inventory problem,"

"determining the profitability of my loans," and "setting the price for my product," are much more specific descriptions of decision makers' needs. These more specific needs correspond very closely to statements of the decision problems themselves, whereas the less specific needs reflect general characteristics of human and organizational problem solving.

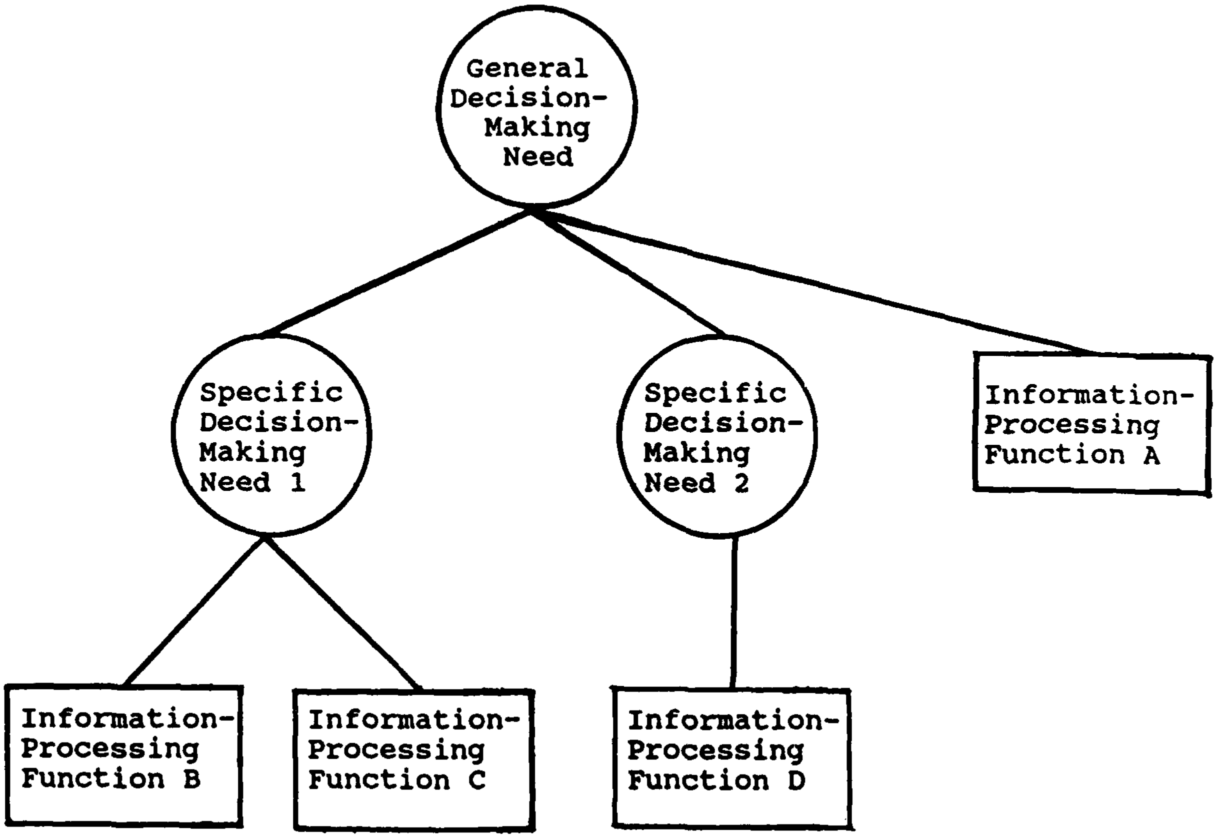
Why speak in general terms at all when we can study more specific decision-making needs? First, the functionality of some DSS can only be described in general terms. Many systems today are intended to be broadly applicable, requiring customization before being applied to particular decision-making situations. Electronic spreadsheets offer a good example; they are "content free" entities, waiting for a user to imbue them with problem-specific content. The decisional needs met by such systems can only be described in the more general terms.

Second, general decision-making needs serve to classify more specific decision-making needs. In fact, decision-making needs can be organized in a hierarchy, with needs at one level refined into more specific needs at the next level (see Figure 4). Special leaf nodes representing information-processing functions can then be attached to those nodes whose needs they satisfy. Moreover, such leaf nodes could be placed at any level of the hierarchy, depending on the degree of specificity of the needs they meet. A small portion of an abstract needs/functions hierarchy is illustrated in Figure 4, where circular nodes correspond to decision-making needs and rectangular nodes represent information-processing capabilities. We see that decision-making needs can be used as a multi-level classification scheme for DSS functionality.

DSS researchers can proceed in two directions along the path of inquiry. They can begin with functional capabilities found currently in Decision Support Systems and attempt to define which decision-making needs those capabilities meet and how they do so. Alternatively, researchers can choose a decision-making need--at any level of specificity--and propose functional capabilities that can satisfy it. Either approach should prove fruitful in developing the tree of decision-making needs and information-processing

Figure 4

Abstract Hierarchy of
Decision-Making Needs and Information-Processing Functions



Explanation. Information-Processing Function A meets the General Decision-Making Need.

Information-Processing Functions B and C meet Specific Need 1.

Information-Processing Function D meets Specific Need 2.

functions. The more expansive the tree, the greater our understanding of the role of information-processing technology in supporting managerial activity.

Summary. The first-tier description of DSS is the one most commonly found in practice today. It is the *sine qua non* of descriptions, for without an understanding of a system's functional capabilities, we can say very little about that system. Augmenting simple descriptions of information-processing activities with analyses of the decisional needs met by each function can increase significantly the value of this first-tier description. The information provided by the first-tier analysis serves as the basis for descriptions at the upper two levels.

4. The Second Tier: User View of System Components

Beyond what it can do, an important aspect of a DSS is how it is organized. A system's configuration can be seen from two different perspectives: the internal view and the external view. The internal view describes the architecture of a system's underlying technological building blocks--in terms of Sprague's (1980) framework, the database, dialog, and model base management components. The external view describes how a system's functional capabilities are packaged--that is, how the system components appear to users. It is the user perspective that is important for our present descriptive purposes, and this view constitutes the second tier of analysis.

A given set of functional capabilities can be packaged for users in a number of ways. For instance, consider the following questions that can be asked about a system's (external) configuration. Do users see discrete operations that can be invoked in any order, or do they encounter a sequence of steps organized in a predetermined fashion? Do users see a modeling capability independent of individual models, or do they access a set of fully-packaged models? Do users employ database and graphics capabilities that exist independently of particular datasets, or do they see a package of particular databases and retrieval capabilities? Can users modify the system's operators, data, models, and

representations? These and similar questions are answered by the second level of analysis.

The second tier clearly builds on the information provided by the first-tier analysis. Since the same basic information-processing functions can be packaged in a variety of different ways, however, the user view represents a significant level of analysis in its own right. The way in which a system's components appear to its users can play a determining role in how that system is used, hence, how it affects decision-making behavior.

In order to satisfy the objective of being able to describe as well as differentiate DSS, it is desirable to define a vocabulary that can be applied to describing the user view of any DSS. We may think of such a schema as a "generic user view."

The generic user view most widely cited in the literature is the ROMC approach (Carlson, 1983; Sprague and Carlson, 1982), which identifies four DSS components: representations, operations, memory aids, and control devices. Representations are visual images corresponding to conceptualizations of information such as tables, lists, graphs, and maps. Operations are the devices invoked by users to perform information-processing activities and may be simple manipulations or may involve complicated decision aids such as simulation models or forecasting models. Memory aids support the use of representations and operations by storing and retrieving information in a variety of manners, and control mechanisms assist the user in directing the use of the DSS. ROMC's proponents assert that one of its chief advantages is allowing users to structure their own decision-making processes--through the selection of operations--as opposed to locking users into a predefined sequence of steps.

While the ROMC approach is quite popular and has a number of appealing characteristics, it has two drawbacks as a generic user view when we wish to analyze DSS in terms of their effects on decision-making processes. First, although ROMC accommodates very well those systems that give users free reign in choosing operations, it cannot be used to describe systems that deliberately limit user discretion in defining decision-making processes. Second, ROMC does not emphasize those DSS components that

are most important for understanding how a system affects its users' decision-making processes.

The new generic user view proposed here--discussed in greater detail by Silver (1986)--also consists of four types of principal components:

- Operators,
- Navigational Aids,
- Adaptors, and
- Sequencing Rules.

Figure 5 provides a schematic illustration of this generic user view of DSS, including these principal components together with their inputs and outputs.

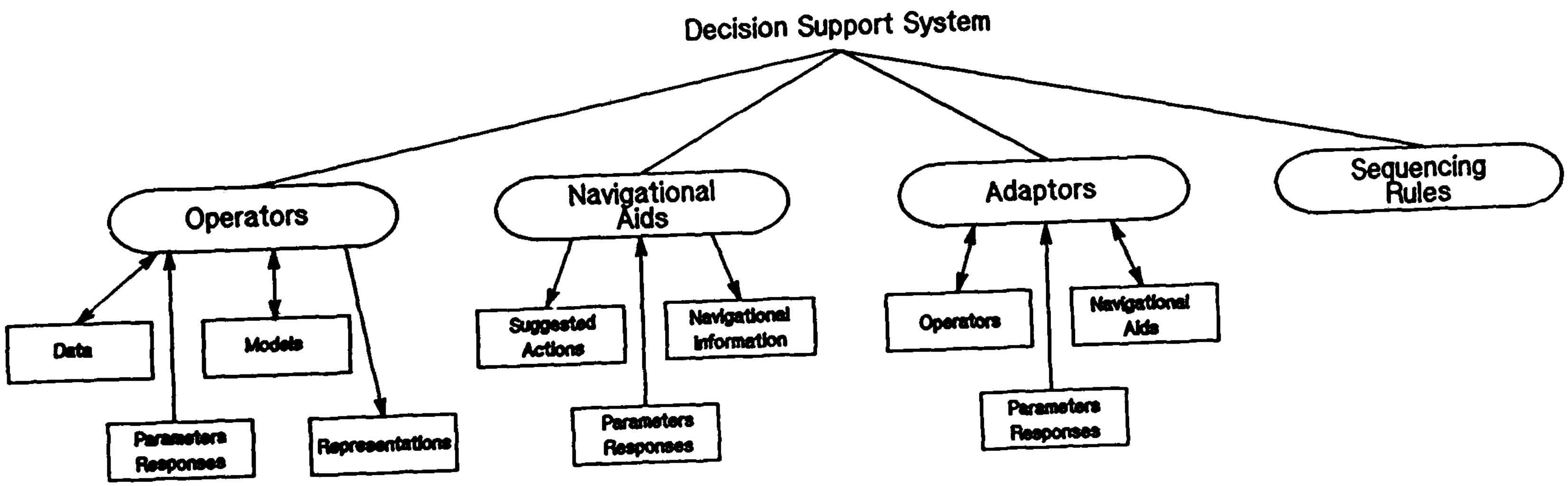
Operators. The workhorses of a Decision Support System are its operators, the devices invoked by users to access the functional capabilities. Commands typically found in DSS--for example, "List," "Query," "Calculate," "Regress," and "Optimize"--are all operators. Operators are comparable to ROMC's operations. Operators are the dominant component here, however, whereas in ROMC, representations dominate. Since operators control a system's information-processing activities, they are central to describing how a system affects decision making.

When an operator requires data or models as inputs, two configurations are possible. Data or models can be embedded in the operator so that users see a single, non-separable entity and cannot manipulate the data or models independently of the operator. Alternatively, data or models can be treated as entities separate from the operator, in which case users must specify the data and models to be used at the time an operator is invoked. The alternative configurations present a trade-off between the ease of use and the flexibility afforded to users. The relative merits of each approach require study.

As an example, consider the production-mix problem. An operator could be defined in at least three different ways: to solve a particular production-mix problem, to solve the

Figure 5

Proposed Generic User View of Decision Support Systems (Second Tier)



generalized production-mix problem with users supplying the problem-specific data, or to solve any linear program with users supplying the data as well as the production-mix model. The first case embeds data and models within the operator, the third case separates both data and models from the operators, and the middle case falls in between, embedding the model but leaving the data separate.

Navigational Aids. Navigational aids assist users in steering through a system and its operators. When using complex DSS that offer many operators from which to choose, simply deciding what to do next may itself be a formidable task. Decision makers may need to choose among competing operators--for example, implementations of different choice rules--any one of which is adequate to perform a particular task. Similarly, users may be uncertain as to which models, data, or representations to employ as inputs to the operators they select. Alternatively, decision makers may know which operators and inputs they intend to use, but be uncertain as to the order in which to use them. Navigational aids that either offer helpful information or suggest possible paths through the system can therefore play critical roles in determining how a DSS is used and, ultimately, how decisions are made.

Context-sensitive help messages and look-ahead menus are simple aids commonly found in systems today. Help messages designed specifically for a user's current location within the system can provide information useful in choosing what course to follow next. Similarly, menus providing a view of the operators available one step beyond the current position also assist users in planning ahead and structuring their use of the system.

Navigational aids come in a variety of forms and can be far more complex than these simple examples. Some navigators provide users with suggested courses of action while others only offer pertinent information concerning possible actions. Some navigators are short range, helping only with choosing the next step, while others are more long range, helping define a longer sequence of activities. Some navigational aids interact heavily with users, while others generate their information and suggestions without user involvement. No

matter what their form, by influencing the selection and use of operators, navigational aids can play critical roles in determining users' decision-making processes.

Navigational aids present a combination of technological and behavioral issues for DSS researchers. The technological challenge is to invent more sophisticated and more supportive navigational aids than are prevalent in DSS today. The related behavioral question is how such aids will affect users' decision-making processes.

Adaptors. An important concept in the literature is the notion that DSS must be "adaptive" in order to support the personal styles of individual decision makers and/or to respond to changes in decision-making environments over time (Keen, 1980). The degree of customizability or adaptivity of a Decision Support System is a function of the power of its "adaptors," devices invoked by the user to modify existing operators and navigational aids or to create new ones. For example, if a system includes an operator that measures angles in degrees, a user might employ an adaptor to modify it to use radians. If a DSS includes matrix algebra functions but does not include a regression operator, a user could employ an adaptor to create the regression operator from the matrix algebra functions. DSS vary widely in terms of the presence, nature, and power of their adaptors.

Sequencing Rules. Operators, navigational aids, and adaptors are all invoked by the user. In contrast, sequencing rules govern the operation of a DSS by the user, determining which of the operators, navigational aids, and adaptors--users are allowed to invoke at any point during a session. More generally, the sequencing rules determine which sequences of invoked devices are legitimate and which are not permitted.

The set of all Decision Support Systems can be partitioned into two classes based on the types of sequencing rules they enforce. If a DSS has a "trivial rule set," then it does not impose any restrictions on the sequence of operators, adaptors, and navigators invoked by users. Any of these devices is available for use at any point in time. If, however, a system uses a "non-trivial rule set," then it limits the sequence of activities in one or more

ways. In this case, different sets of operators, adaptors, and navigators are legitimate for use at different points in time.

Non-trivial rules can limit users in a number of different ways. Some rules may limit what can be done next based only on what the user did last, whereas others may consider the entire sequence of previous activities. Some rules may depend only on the identity of operators invoked previously, while others may also depend on the results they returned. Some rules may constrain only which operators can be used next, whereas others may constrain the inputs as well.

A variety of purposes can be served by employing non-trivial rule sets to constrain decision-making processes. For instance, a sequencing rule might require projected budgets showing deficits to be balanced before a user can invoke any other operators. Similarly, a rule might require users to examine sensitivity information after running linear programs whose results are not very robust. Clearly, the set of sequencing rules can play a major role in determining the effect a DSS has on decision-making processes.

It is the concept of sequencing rules that allows this generic user view to handle systems that are not describable by ROMC. ROMC, by intention, describes only those DSS with trivial rule sets. There is no ROMC mechanism for capturing the role of non-trivial sequencing rules in a DSS.

Sequencing rules raise research questions similar to those of navigational aids. On the one hand, there is the technological concern of how to build systems with complex, non-trivial rule sets. The technology is only useful, however, if we also have a handle conceptually on the types of information-processing and decision-making constraints those sequencing rules should implement.

<u>Summary</u>. The second-tier analysis builds on the previous level's description of functional capabilities to capture how a Decision Support System's components appear to its users. This level of analysis corresponds to an important set of alternative configurations for packaging a system's functional capabilities. To facilitate describing and differentiating

DSS at this analytic level, a generic user view is a valuable mechanism. The generic user view proposed here--consisting of operators, navigational aids, adaptors, and sequencing rules--contrasts with the popular ROMC approach by emphasizing those system components that play a determining role in the effect a DSS has on decision-making processes.

5. The Third Tier: System Attributes

When we view DSS as interventions into decision-making processes, we are more concerned with the questions "How is the DSS likely to affect the user's behavior?" and "What is the user likely to do with the system?" than we are with the questions "What can the system do?" and "What does the system look like?" We shift our attention from the system to the decision maker, considering how users can and will integrate the DSS into their decision-making processes. In so doing, we move beyond considering individual functional capabilities and how they are configured to studying attributes of the system as a whole. These system attributes constitute the third descriptive tier.

The third tier builds on information provided by the lower two descriptive levels to analyze how the parts of a DSS fit together synergistically to form a whole whose effects on decision making can be different from the sum of those of its parts. The attributes represent collective statements about the components of a DSS and the relationships among them. For instance, attributes indicate whether a system's information-processing functions complement one another, substitute for one another, or are unrelated to one another. Attributes capture if and how a DSS allows users to combine individual capabilities. Attributes also identify whether the whole decision-making process or only a portion thereof is supported.

Three such system attributes (Silver, 1986) are defined and discussed here:

- System Restrictiveness,
- System Guidance, and
- System Focus.

<u>System Restrictiveness</u>: the degree to which and the manner in which a Decision Support System restricts its users' decision-making processes to a particular subset of all possible processes.

Decision Support Systems are usually viewed intuitively as augmenting decision makers' capabilities, not as limiting their decision-making processes. This position must be modified, however, by recognizing that a DSS actually intervenes in the processes through which decisions are made. To the extent that decision makers rely on DSS in solving their problems, the specifications of these systems can, in fact, be a limiting set of features.

DSS are frequently implemented in situations where unique, well-defined decision-making processes do not exist. In these cases, either there is no well-defined method for solving the problem or there are multiple, competing solution techniques. One-time decisions, such as deciding where to locate a nuclear power plant, illustrate the former case. The many competing multi-criteria decision making techniques proposed by operations researchers and the various alternative descriptive models of individual choice studied by behavioral decision theorists offer examples of the latter case.

In situations such as these, where defining an appropriate decision-making process is itself a major concern, which features are included in a DSS and which are excluded play a critical role in determining the process that is ultimately followed. Nonetheless, when analyzing Decision Support Systems, we tend to focus only on the question "What features are to be built into the system?" and disregard the question of "What features are not to be included?" If our purpose is simply to describe what the system can do, then answering only the first question may be adequate. If we wish to understand how the system affects decision-making processes, however, both questions are equally important. For instance, if a DSS supports many processes but does not support the current decision-making process, then recognizing what has been excluded from the system is surely as crucial to the analysis as knowing what has been included.

DSS vary significantly in terms of how restrictive they are and how they are restrictive. In general, since decision-making processes are sequences of

information-processing activities, DSS restrict processes by limiting the set of information-processing sequences users can perform. The generic user view proposed earlier provides a language for describing more specifically the various ways that the features of DSS can be restrictive.

First and foremost, the set of **operators** can be restricted. For instance, to cause decision makers to use the "elimination by aspects" (Tversky, 1972) heuristic rather than "multi-attribute utility" models, operators supporting the former approach are included while those necessary for the latter technique are excluded. Second, for those operators included in the DSS, the **inputs**--especially **data** and model **parameters**--can be limited. For example, regression analysis might be included in a DSS but certain datasets might not be permitted as inputs to the regression operators. Third, the system can employ **non-trivial sequencing rules** to constrain the order in which operators can be used. For instance, a sequencing rule might require that when Durbin-Watson statistics show autocorrelation, data must be transformed before running regressions. Finally, the ability of users to modify and or expand the set of operators can be limited by restricting the system's **adaptors**.

While more research is required to make prescriptive claims concerning how much and what form of restrictiveness is appropriate in a given situation, one can identify a number of factors favoring greater or lesser amounts of restrictiveness. Two important factors that often favor increased restrictiveness for a DSS are a need to prescribe a particular approach to decision making and a need to proscribe a particular problem-solving approach. That is, a system can be designed to impose a normative approach to decision making, on the one hand, or a system can be constructed to prevent decision makers from using some undesirable approach, on the other hand. A third factor favoring more restrictive DSS is a concern not to overload and overwhelm decision makers with large sets of capabilities; limiting the available techniques can promote structure in decision-making processes.

The factors favoring restrictiveness are weighed against a set of factors opposing

restrictiveness. The desire to foster greater flexibility leading to enhanced creativity and exploratory learning--two often-cited DSS objectives--suggests building a DSS that is less restrictive. So, too, does the intention to implement a system than can be applied easily to new and or changing decision-making environments. The most important reason for making a DSS less restrictive, however, is that excessive restrictiveness may prevent use. If decision makers feel uncomfortably restricted by a system, they may choose not to use it. No matter how compelling the reasons are for restricting, a system will not accomplish its objectives if it is never used.

> **System Guidance: The degree to which and the manner in which a Decision Support System guides its users in constructing and executing decision-making processes, by assisting them in choosing and using its operators.**

Providing decision makers with flexibility in the use of their Decision Support Systems is often claimed to be an important element of DSS design. When a significant amount of flexibility is offered by a DSS, however, mechanisms may be required for helping decision makers take advantage of--read, cope with--the discretionary power they have been given in controlling the operation of the system.

Any computer-based system that allows its users to choose among different operators, datasets, or models must provide them with some means of communicating their selections. Menus and command interpreters represent typical devices for accomplishing this task. When an interactive system contains numerous operators, datasets, or models, it may be desirable to augment these technologically-necessary selection devices with facilities for helping users determine what to do next. Context sensitive help messages, for example, have become commonplace means of assisting users to navigate through complex systems.

The need for assistance is particularly great in systems supporting decision making. Often the "meta-choice" decision of "deciding how to decide" is the most difficult part of solving a problem, as decision makers may confront many tough questions in selecting

appropriate solution procedures for their problems. For instance, given a particular multi-attribute problem, should a process method or a scoring method be used to choose among alternatives? Should a compensatory or non-compensatory rule be used? Should a serial approach be used where solutions are generated and evaluated one at a time, or should a parallel process be employed where a set of alternatives is generated and one course of action is then selected from among these candidates?

When a DSS supports many different solution techniques by including a variety of different operators, datasets, and models it may also provide support for the "meta-process" of structuring the decision-making process. More than simply helping users navigate through complex systems, such assistance is based on decision-making considerations, such as those just enumerated for multi-attribute problems. In particular, such guidance addresses the decisional relationships among operators such as which operators function as substitutes and which as complements within coherent decision-making processes. Such guidance is implemented--in the language of the generic user view--through navigational aids in the DSS.

Just as assistance in selecting operators and structuring decision-making processes can be valuable, so too can computer-based support for using the selected operators and executing the decision-making processes. The conventional wisdom concerning DSS is that they combine the best features of humans and machines. According to this view, human decision makers typically perform the judgmental tasks, while the machines perform other information-processing activities. Nonetheless, human decision makers can benefit from computer-based assistance at those points in the decision-making process where they must execute judgment.

Consider, for example, a decision maker who elects to employ an elimination by aspects approach to choosing a city in which to live. A simple DSS for implementing this choice rule might allow its users to enter attributes and acceptable ranges for their values, producing a list of those cities satisfying the specified criteria. While such a system does

aid decision makers by performing the necessary database searches, it does not assist with the critical judgmental tasks of choosing and ordering attributes and defining value ranges. Another--perhaps more supportive--system might provide such judgmental assistance.

The need for navigating through a complex system, the need for structuring a decision-making process, and the need for executing judgment all provide opportunities for including guidance mechanisms in a DSS. DSS will vary greatly in terms of the extent and nature of the guidance they offer. Since the guidance a system provides can have a major impact on the processes through which decisions are made, the system guidance attribute plays a key role in describing and differentiating DSS in terms of their effects on decision making.

There is an important interaction between the restrictiveness and guidance attributes. The more restrictive a Decision Support System is, the less discretion the user has, hence the less room exists for meaningful guidance. DSS builders wishing to influence decisional behavior therefore confront a fundamental design decision: whether to impose decision-making processes through restrictiveness or to propose decision-making processes through guidance.

> **System Focus: The degree to which and the manner in which a Decision Support System's operators provide specialized support for decision-making processes.**

An important property of a Decision Support System is the degree to which it is customized for the particular decision-making environment(s) it supports. To a large extent, the customization of a DSS is determined by the specialization of its operators. The focus attribute makes a collective statement about the degree and manner of decisional specialization of a system's operators.

In general, an operator's specialization can be identified simply in terms of its inputs, its outputs, and how it transforms the former into the latter. The inputs and outputs define what the operator does and the transformation determines how it does it. When

studying DSS operators, however, more needs to be said. Capturing the specialization of an operator requires describing its distinctiveness not in the language of computer science or mathematics but in the language of decision making. One must be able to characterize the ways in which it does and does not contribute to solving decision-making problems.

Consider, for example, a pair of operators implementing multi-attribute utility theory and elimination by aspects, respectively. Functionally, both take a set of alternatives with associated attribute values as inputs and produce a single alternative as an output. From a decision-making perspective, however, the operators would be described as implementations of decision rules executed during the "choice" phase of a decision-making process. Moreover, multi-attribute utility theory would be characterized as a compensatory scoring method, whereas elimination by aspects would be classified as a non-compensatory process method. These descriptions offer a good deal of information concerning the role the operators play within decision-making processes.

The general wisdom concerning DSS is that the more focused or specialized an operator, the more supportive it can be of decision makers. Nonetheless, DSS vary widely in terms of how focused their operators are. Any given DSS is itself likely to have a significant mix of focused and unfocused operators. When a DSS contains a preponderance of focused operators, we refer to the system as a whole as focused.

Operators can be focused in many ways. Any concept that classifies decision-making environments or partitions decision-making processes can serve as a dimension for analyzing focus. For instance, Huber (1981) has suggested that different decision aids are appropriate for different organizational decision-making styles. Such specialized aids would then be focused on either rational, programmed, political, or garbage can environments. Similarly, operators can be focused on particular functional areas, such as Finance or Marketing.

A special dimension of focus is the phase of decision making. Using Simon's (1960, 1977) "Intelligence," "Design," "Choice," and "Review," model--or any of the other stage models--one can analyze whether or not a system's operators are tailored for particular

phases of the decision-making process. If so, then the system is focused with respect to phase. An important question to ask of such focused systems is whether or not they are "complete." That is, are they "soup-to-nuts" DSS with at least one operator for each phase, or are they fully specialized DSS, with all operators concentrating on a single phase.

When a significant proportion of a DSS's operators are focused with respect to one or more dimensions, it becomes possible to analyze that system in terms of the relationships between its operators. For instance, one can speak of operators being substitutes for one another, complements to one another, or unrelated to one another. Such analyses provide both a deeper understanding of the synergistic nature of the DSS as a whole and greater insights into the role the system can play in supporting the decision-making processes of its users.

Summary. The analysis of system attributes culminates the three-tiered analysis, building on the informational content of the first two tiers to characterize how a Decision Support System, when considered as a "whole," is likely to affect the decision-making processes of its users. This uppermost analytical tier concentrates on how a system can be used by decision makers, rather than on what a system can do. Each of the three system attributes contributes a different collective statement about the system's decisional features. While all three attributes can be applied to any DSS, system restrictiveness and system focus are the most relevant for analyzing today's DSS, since most systems currently in place contain relatively little of the "meta-support" captured by the system guidance attribute.

6. Research Implications

The three-tiered descriptive schema has numerous implications for continued DSS research. Some of the research issues that follow consist primarily of further development of the schema, while others represent applications of the schema to existing DSS research problems. Naturally, there is some overlap between these two endeavors.

<u>**The Three Tiers**</u>. Our understanding of each of the three descriptive tiers can benefit from additional research. The chief research activity at the first tier is matching information-processing capabilities with decision makers' needs. Such research can lead both to a better understanding of how existing information-processing capabilities support managers as well as to the invention of new and more supportive capabilities.

Research at the second level tends to integrate technological and behavioral issues. The challenge is to devise and implement new DSS components--for instance, new types of navigational aids or new forms of sequencing rules--that accomplish particular objectives in terms of their effects on the problem-solving behavior of their users. Another research topic at this level is to understand better the trade-offs among alternative configurations of components. For example, what are the relative merits of embedding data and models in operators versus keeping them as separate entities?

Each of the three system attributes--restrictiveness, guidance, and focus--can serve as the basis for further descriptive, prescriptive, and technological research. The purpose of additional descriptive studies is to understand better the effects that the attribute has on decision-making behavior. For instance, how much and what forms of restrictiveness tend to inhibit system use? Similarly, what forms of guidance are most likely to influence decision makers and how? Based upon the results of the descriptive studies, the next set of issues are prescriptive. Once we understand how the attributes affect decisional performance, we can prescribe the forms of restrictiveness, guidance, and focus that are appropriate in a given situation. Finally, technological questions still remain concerning how to implement DSS possessing the desired restrictiveness, guidance, and focus.

<u>**The DSS as a Research Variable**</u>. Recalling Figure 2 and the various research questions it suggested, notice the pivotal role played by the Decision Support System. The DSS serves both as the output of the systems analysis and design process and as an input to the process of system use. In a large number of DSS research studies, therefore, the key variable is the DSS itself.

Sometimes, the DSS is the dependent variable, as in the question "Do different analysis and development processes systematically produce different types of DSS?" Other times, the DSS is the independent variable, such as when we ask, "Are some types of DSS more likely to be used than others?" In the former case, it is important for us to examine a collection of DSS and describe systematically how they differ from one another. In the latter situation, we need to be able to vary the features of DSS systematically.

The descriptive approach proposed here gives researchers both of these analytic capabilities. Moreover, the three separate tiers can help to isolate particular phenomena of interest. For example, the functional capabilities can be held constant (first tier), while their packaging (second tier) is varied. The three-tiered mechanism should therefore serve as a foundation for studying many of the contingencies associated with DSS development and use.

Perhaps the most fundamental of all DSS research questions is "How do DSS affect the decision-making behavior of their users?" More precisely, we are interested in understanding how different DSS affect decision-making processes differentially. The three-tiered schema should prove especially useful for addressing this question, because in developing the schema great emphasis was placed on identifying those characteristics of systems that are determinants of decision-making behavior.

When studying the effects of DSS on decision-making behavior, the DSS usually serves as the independent variable and we concentrate on the third tier of the schema. One of the three attributes--restrictiveness, guidance, or focus--is selected for study, and the other two attributes are held constant. Several DSS are acquired that differ only in terms of the attribute under consideration. By studying the decision-making processes and decisions of subjects using different systems, we can detect the effects of variations in the particular attribute. Of course, determining which aspects of decision-making processes to analyze depends on the specific research objectives.

As an illustration, consider research concerning the effects of DSS on systematic

cognitive biases in decision-making processes. Researchers in Behavioral Decision Theory have observed that human problem solvers exhibit a number of systematic cognitive biases in making decisions. That is, humans systematically misprocess information--often probabilistic information--in performing decision-making tasks. Literally dozens of such biases have been studied in the literature (Tversky and Kahneman, 1974; Kahneman, Slovic, and Tversky, 1982; Sage, 1981; Hogarth and Makridakis, 1981).

Several researchers have raised the question of the relationship between DSS and cognitive biases (Kydd and Aucoin-Drew, 1983; Wright, 1983; and Schocken, 1985). One question we can consider is whether computer-based systems may in fact foster some of these biases. Another question is whether a computer-based aid can be used to debias a decision maker--that is, to offset or correct for the biased processing of information. In particular, one might hypothesize that particular forms of DSS restrictiveness can be used to reduce biased information-processing by proscribing activities that can lead to biased behavior. A researcher could examine such a hypothesis by first studying the biases exhibited by users of a particular DSS, then varying the restrictiveness of the system, and finally studying the biases manifest by users of the revised system.

A Prescriptive Mapping. The descriptive schema proposed here represents a major step in the direction of a prescriptive mapping from decision-making environments to Decision Support Systems. Of course, considerably more research must be performed before we will be in a position to offer significant prescriptions concerning what types of DSS should be built for particular types of decision-making environments. Indeed, we still must find an appropriate way of describing and differentiating the elements of decision-making environments: the people, tasks, and organizational settings. The descriptive mechanism for DSS may help with this endeavor, as well, by providing a means for evaluating the various approaches that have been proposed in the past for characterizing decision-making environments. Those environmental characteristics that are shown to have meaningful implications in terms of the three-tiered analysis should be seen as the most

promising bases for prescription.

__Development Systems for DSS__. A number of different software approaches can be used to develop DSS. One means of implementing DSS is by using general-purpose languages such as Fortran and APL. Alternatively, Sprague (1980) has advocated building specific DSS from "DSS Generators," packages of related hardware and software capabilities that enable builders to construct DSS quickly and easily. More recently, Ariav and Ginzberg (1985) have identified "Generalized DSS," systems that provide support for a particular class of decision problems, as another resource for constructing specific DSS.

The three-tiered schema is used to describe specific DSS, not the development systems from which they are created. Two open and important research questions, therefore, are how to describe the characteristics of development systems and how these characteristics of development systems are reflected in the DSS they produce. More specifically, we need to know how the functional capabilities, user views, and system attributes of a DSS are determined by the characteristics of the software system that produced it. One element of such research is to understand how the characteristics of existing DSS Generators and Generalized DSS affect the DSS they produce. Another aspect of the research is to consider how new DSS development systems can be designed that produce DSS with particular features--for instance, DSS with non-trivial sequencing rules or DSS with extensive guidance.

__Artificial Intelligence Methods__. Recently, the DSS community has expressed great interest concerning Artificial Intelligence (AI) techniques, in general, and Expert Systems (ES) and inference mechanisms, in particular. For DSS researchers, the chief question is how these new and exciting underlying technologies can be employed to build computer-based systems that are more supportive of decision makers. The descriptive schema can be invoked to transform the issue into three more specific questions.

First, how can AI and ES techniques be used to create new functionality in DSS?

As one example, an inference engine together with a suitable knowledge base could be used to analyze historical databases and identify important trends for decision makers. Turban and Watkins (1986) have surveyed a number of functions that Expert Systems technology can perform for Decision Support Systems.

Second, how can AI and ES techniques be used to implement particular components of DSS? Typically, new functionality will be implemented as individual operators. But what about the other components of DSS? Both navigational aids and sequencing rules are difficult components to implement and are prime candidates for the use of AI/ES methods. Both require the DSS to draw context-sensitive conclusions and could be implemented as "mini" production systems. For instance, a navigational aid that suggests which operator to invoke next could be based upon a set of production rules. These rules might be defined in advance by the system builder or might even be derived by the system during the course of system use. Similarly, a rule-based system embedded within the DSS would be ideal for implementing complex, non-trivial sequencing rules.

The third question is how embedding AI and ES techniques in a DSS can affect the system's attributes. For instance, when a "mini" expert system is built into a DSS, the expertise can be implemented in the form of restrictiveness, imposing results on decision makers, or in the form of guidance. Similarly, if an expert system is implemented as a source of guidance to users, that guidance may either be in the form of pertinent information intended only to enlighten the decision maker, or in the form of suggestions intended to influence the decision maker. These alternative approaches to embedding expert systems in DSS and their effects require more extensive study.

7. Conclusion

The three-tiered descriptive schema presented here satisfies the objectives set forth at the outset: enlightening research and practice, facilitating communication among researchers and between researchers and practitioners, distinguishing as well as describing DSS, and understanding DSS in terms of their effects on decision-making processes. At each level

of the schema, the descriptions highlight characteristics that distinguish DSS from one another. Each analytical level also considers the features of DSS in terms of decision-making behavior, with increased attention being paid to the effects of systems on decision-making processes as one moves up the tiers. Moreover, each level builds on the information provided by its predecessors.

The first and second descriptive tiers are the ones most commonly used today, with the first level typically receiving greater attention than the second. The value of describing functional capabilities--the first level--can be increased by augmenting such descriptions with an analysis of the general decision-making needs addressed by the information-processing functions. Similarly, the user view of a DSS--the second tier--can be described more effectively by using the proposed generic user view, which recognizes the importance of navigational aids, adaptors, and sequencing rules in addition to operators.

The third descriptive tier--system attributes--represents the greatest departure from the way DSS have been analyzed to date. Studying the properties of DSS considered in their entirety is critical to understanding the effect a system will have on the processes through which decisions are made. It is the collective effect of a system's operators, the synergistic combination of a set of packaged, functional capabilities, that is of primary importance when performing either *ex ante* or *ex post* analyses of the effects of Decision Support Systems on decision-making processes.

The proposed three-tiered approach is a first step toward better and more complete description of Decision Support Systems. As such, it highlights many of the substantive issues in the field of DSS and can serve as the basis for significant research in the future.

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